SNOWSTORM OF FEBRUARY 1-5, 1956, IN NEW MEXICO AND TEXAS

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1. INTRODUCTION

The heavy snowfall in eastern New Mexico and northwestern Texas during the period February 1–5, 1956 was chosen for study because of the rarity of the event and the apparent difficulty in forecasting such an occurrence. This article proposes to summarize the weather and its effects and then to associate the weather with the analysis in an essentially qualitative manner. As this is done the forecast problem will be defined and then the prognosis problem will be discussed.

2. WEATHER

The snowstorm which moved through New Mexico and the northwestern part of Texas may be divided into two sections. One was February 1–3 as the snowfall progressed north to south through New Mexico, and the other February 3–5 as the area of the snowfall remained rather stationary over the southeastern corner of New Mexico and part of northwestern Texas.

By 0030 GMT on February 1 rain was falling at Albuquerque and snow was reported through the northern part of the State, through Colorado, and into western Kansas. By 0330 GMT snow was beginning in the Texas Panhandle and was edging farther southward in New Mexico. By 0030 GMT on the 2d it was snowing in Mexico with the largest snowfall in western New Mexico and lesser amounts elsewhere, e. g., 5 inches at El Paso. Over in the Panhandle and the South Plains of northwestern Texas the snowfall was lighter with amounts ranging from a trace to 2 inches. As the snow moved down over the area, cold temperatures (see fig. 1) and winds with gusts of 30–50 knots were reported. The temperatures were generally in the lower 20's and the winds whipped the snow around to reduce the visibilities to near zero; a real blizzard had moved into the country. At this stage of the storm considerable hardship was experienced by people who lived in the vicinity of Albuquerque and southward to El Paso. The snow drifts closed highways and blocked city streets seriously handicapping travel.

By 1230 GMT of the 3d the snow had tapered off over the western part of New Mexico, but in an area roughly bounded by Wink-Lubbock-Amarillo-Tucumcari-Roswell-Wink, snow fell almost continuously until 0630 GMT, February 5. From then on until 0030 GMT, February 6 the snow gradually decreased from west to east. On the 3d the second part of the storm began as the biggest increase of snow was felt in the southeastern part of New Mexico and the snow both there and in Texas was wetter than that which had previously fallen in this area. On the 4th the biggest accumulation of snow was in the Panhandle and South Plains of Texas.

The snow depth broke records of 50 years duration, and the combination of snow, cold, and winds caused blizzard conditions and considerable hardship. At least 18 deaths were attributed directly to the storm. The normal life of the area was completely paralyzed during the storm and there were still transportation difficulties up through February 14. Highway travel was stopped as drifts blocked the roads and even intercity buses suspended operations after several buses were stranded and the passengers rescued by tractor.

At Clovis, N. Mex., the Santa Fe Railroad sent a special one-car train to pick up stranded motorists between Clovis and Hereford, Tex. The personnel at the Clovis Air Force Base did much to relieve the hardships of the stranded

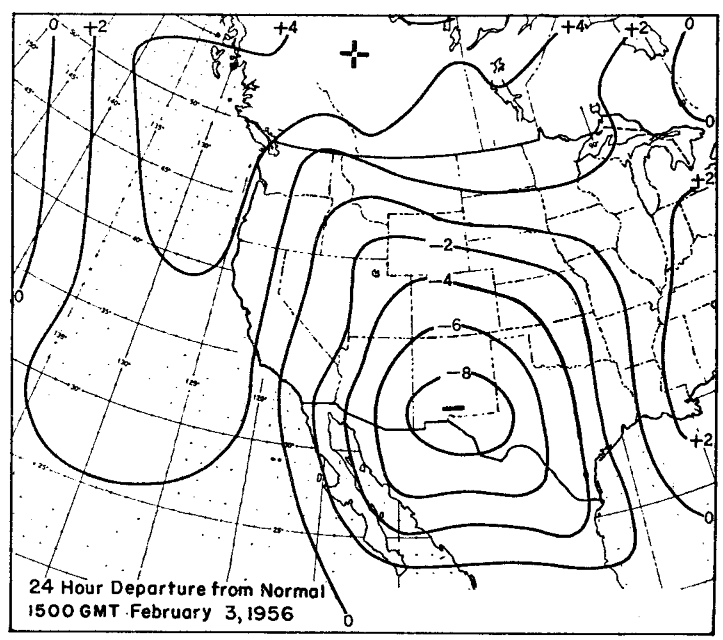

FIGURE 1.—24-hour 1,000–500-mb. departure from normal for 1500 GMT, February 3, 1956. Thickness lines give a good indication of the temperature field. (c. f., Kibler et al. [1]).

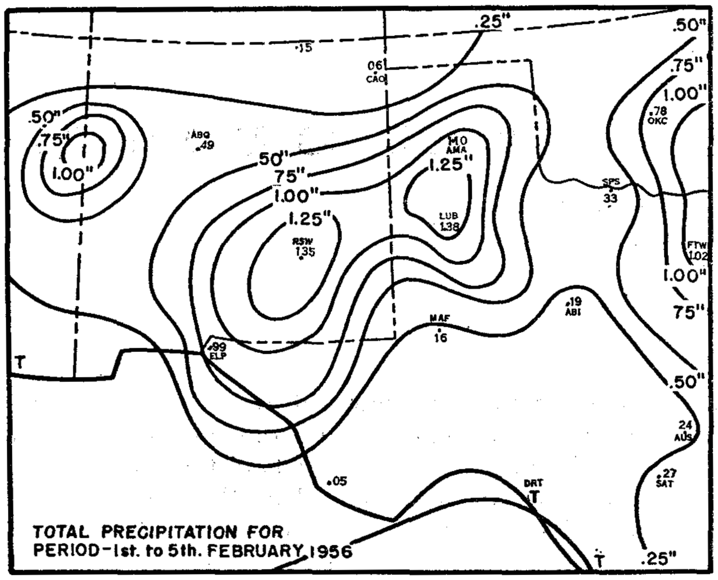

FIGURE 2.—Total-storm isohyetal map for the period February 1–5, 1956.

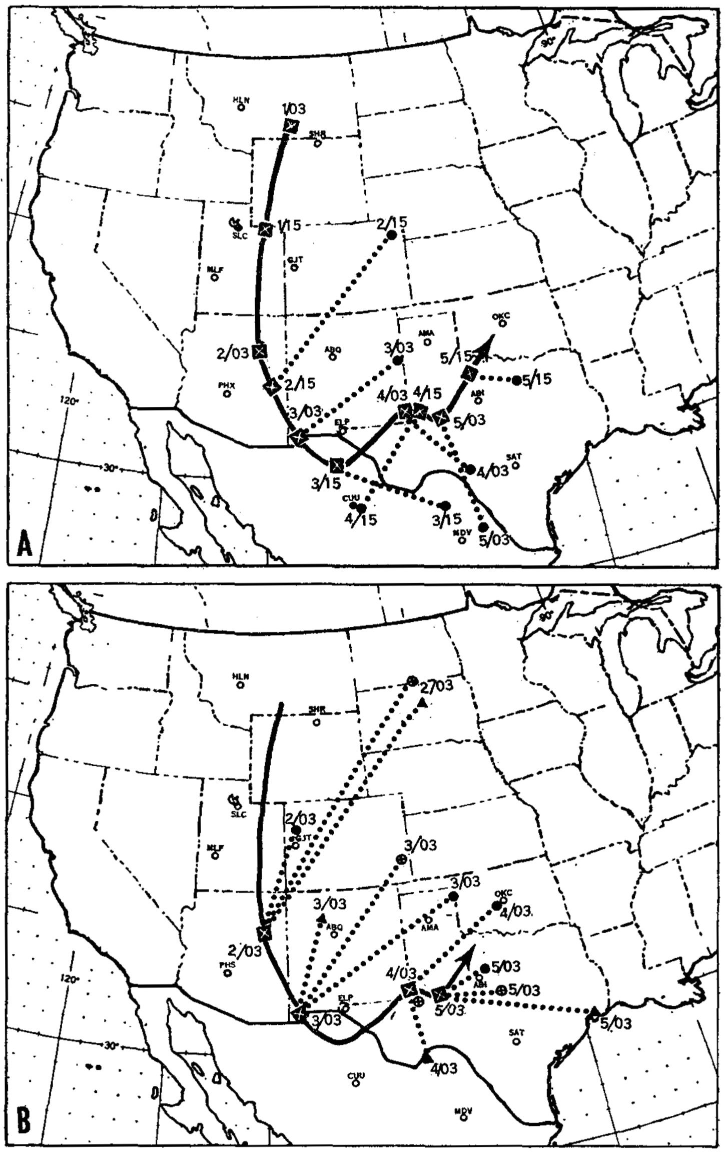

FIGURE 3.—(A) Comparison of the 500-mb. track of the cold Low with the positions as computed by use of the Wilson technique [15]. ⊠ = Observed track. ● = Position as given by the Wilson computation. (B) Comparison of the 500-mb. track of the cold Low with the positions as forecast by various methods. ⊠ Observed 24-hour positions. ● Positions as forecast by the 36-hour baroclinic prognostication (JNWP). ⊗ Positions as forecast by the 36-hour NWAC prognostication. ▲ Positions as forecast by the 48-hour barotropic prognostication (JNWP).

motorists by bringing them to the base for food and shelter until the highways were opened. A cross-country bus, stalled in a snow drift 9 miles from the Texas border, was without heat or food for its passengers. The driver fought his way through the snowstorm to arrive at the border town of Glenrio, "almost frozen", so he might get aid to the people in this bus. In the metropolitan centers of the region many stores were closed, schools shut down for the day on February 3, and many of the main streets were completely blocked by the accumulation of snow.

The snow gave promise of replenished soil moisture where it lay more uniformly over the ground, but much of its value was lost where the wind removed it from the fields and drifted it on the highways and in the ditches. The water equivalent of the total accumulation for the five days was appreciable as is indicated by figure 2. As is clearly shown, the largest amounts were in the area where snowfall was almost continuous for nearly all of the 5-day period. The accumulation was due primarily to the duration of the fall and not the intensity. The 6-hour amount was 0.49 inch at Lubbock from 1830 GMT, February 3, to 0030 GMT, February 4 while most 6-hour amounts were less than 0.10 inch. At no time was the water content of the snowfall what one could consider as high.

3. THE ANALYSIS

The pattern and sequence of weather as described were associated with the movement of a mid-tropospheric cyclone or cold Low, hereafter referred to as the Low aloft (see fig. 3). This movement consisted of three parts: (1) The southward plunge of the Low aloft into Mexico prior to 1500 GMT, February 3; (2) The movement and stagnation over northwestern Texas, 1500 GMT, February 3 to 0300 GMT, February 5; (3) The acceleration in an east-northeast direction after 0300 GMT, February 5. During part (1) the Low aloft filled some, e. g., the 17,800-ft. contour shrank to the size that the 17,600-ft. contour had earlier; and during part (2) the Low maintained its intensity. As the Low aloft moved southward, it was accompanied by a surface ridge coming southward to the east of the Rockies (fig. 4A). During parts (2) and (3) the surface circulation gradually changed to a more cyclonic flow and by 1230 GMT, February 4 (fig. 4B) the Low aloft nearly reached to the ground. The surface temperatures gradually rose during this weak cyclogenesis.

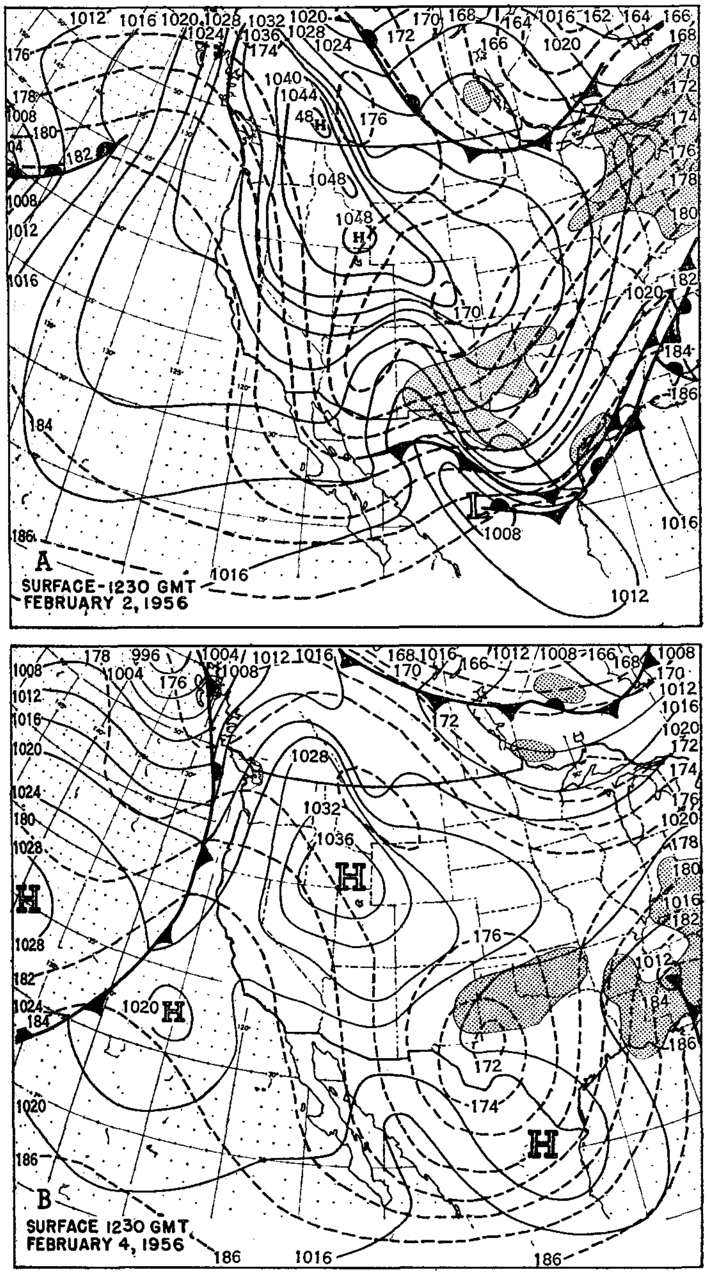

FIGURE 4.—Surface charts with the 1,000–500-mb. thickness (dashed lines) labeled in hundreds of feet. Shading shows areas of active precipitation. (A) 1230 GMT, February 2, 1956 (B) 1230 GMT, February 4, 1956.

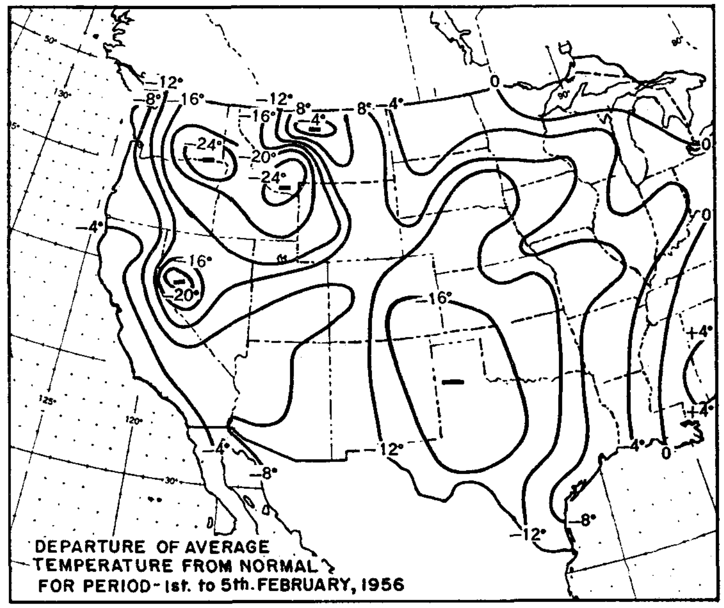

FIGURE 5.—Departure of average temperature from normal (° F.) for the week ending at midnight, local time, on February 5, 1956.

As the first step in examining the association of the weather with the Low aloft, the moisture supply that was available to the area was investigated by charting the precipitable water. By use of a template devised by Showalter [2] the amount of precipitable water in inches was read directly from the plot of the dew point curve on the plotted pseudoadiabatic diagrams. Throughout the period, the amount of precipitable water was rather evenly distributed vertically in all of the soundings in the area, with any appreciable decrease in the amount occurring above 500 mb. All soundings were evaluated from the surface to 400 mb. As would be expected from the cold surface temperatures that prevailed (fig. 5), the amounts of precipitable water were always small. A comparison of the precipitable water charts (figs. 6–9) shows little variation of precipitable water in the area of precipitation being considered here. In fact, the maximum amount of 0.46 inches was available at Amarillo on the 1st, when Amarillo had only a trace of snow. Between February 1 and 2 precipitable water decreased some as drier air came into the area from the north as the Low aloft and the Arctic front pushed southward. From February 3 to February 5 the amount of moisture available was very nearly constant, e. g., 0.24–0.30 inch at Amarillo.

To demonstrate the early drying and then how the constant moisture supply was maintained, 850-mb. and 700-mb. trajectories for 24 hours prior to their termination at Amarillo were plotted on the precipitable water charts for February 2–4. Although these trajectories do not give the path of an air particle, they suffice for the purpose here. The trajectories at 700 mb. are generally representative of the flow above 7,000 ft. which was predominantly southwesterly throughout the period. It is seen in figures 7, 8, and 9 that this was always a drying flow. The 850-mb. trajectories are generally representative of the flow below 7,000 ft. and with time they changed from northerly to more easterly so as to come from more moist areas. The relatively constant moisture supply above 7,000 ft. appears to have been maintained by the upward flow of moisture from the lower level. It appears that the increase in snow amounts on February 4 cannot be accounted for by just an increase in the moisture supply.

Since the freezing level throughout the period was at the ground, it was probable that condensation would result in

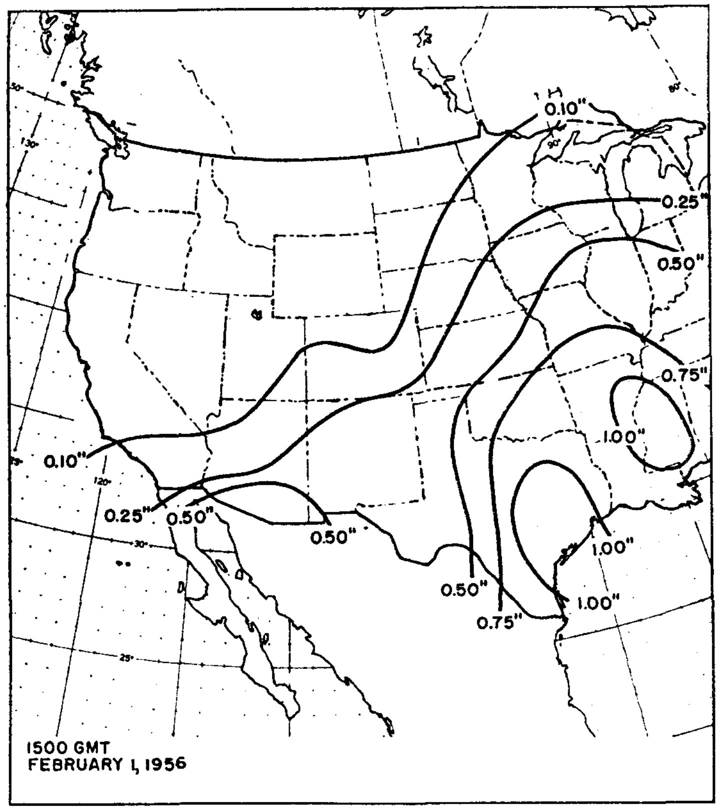

FIGURE 6.—Computed precipitable water in inches at 1500 GMT' February 1, 1956.

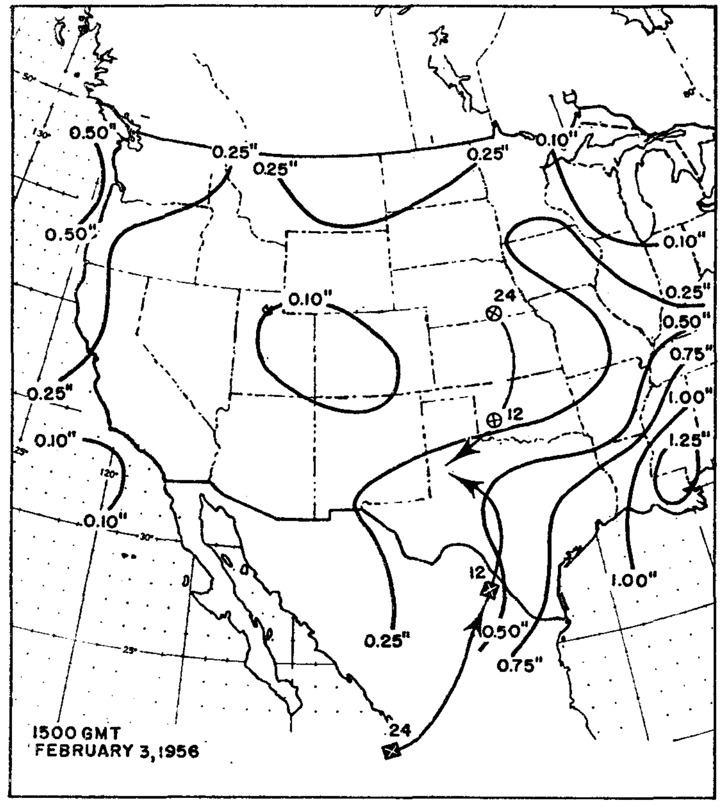

FIGURE 8.—Computed precipitable water in inches with trajectories as in figure 7 at 1500 GMT, February 3, 1956.

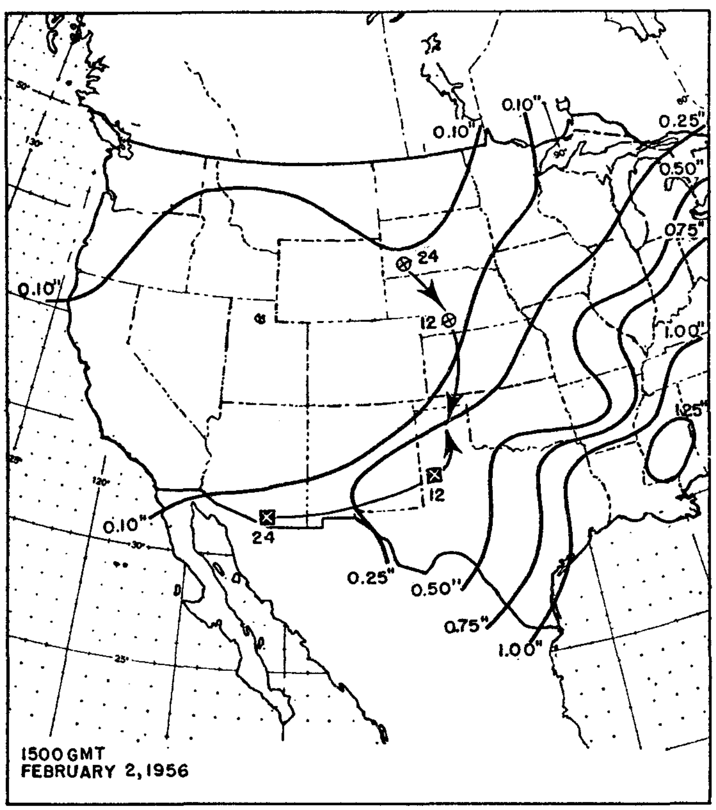

FIGURE 7.—Computed precipitable water in inches with ⊗ trajectories for the 850-mb. flow and ⊠ trajectories for the 700-mb. flow for 24 hours previous to termination at Amarillo at 1500 GMT, February 2, 1956.

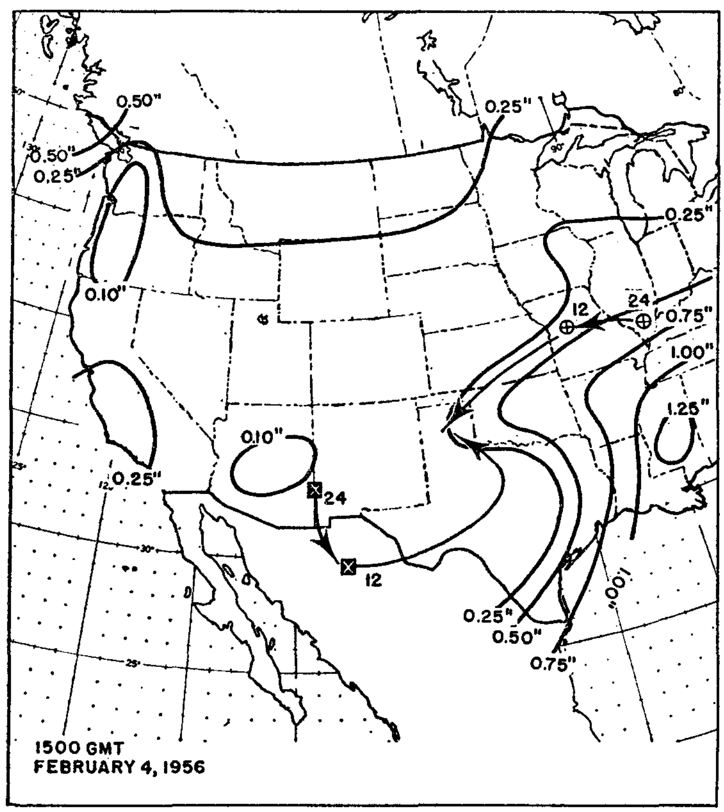

FIGURE 9.—Computed precipitable water in inches with trajectories as in figure 7 at 1500 GMT, February 4, 1956.

snow. The problem of explaining the snowfall reduces to that of explaining the lift needed for condensation and the variations in the lift.

From the fact that the snowfall intensities were light, and that only continuous snow was reported, it may be assumed that convective activity was not present in the particular area of eastern New Mexico and northwestern Texas. This is what would have been expected from the Showalter stability index which was never less than +9 and reached a maximum of +24. In the area to the west of Albuquerque the possibility exists that the snowfall amounts were increased by instability because at 1500 GMT, February 1, the stability index was zero at Albuquerque and snow showers had been reported earlier in extreme northwestern New Mexico. Thus the vertical velocities as determined from the horizontal divergence measured on the synoptic scale [3] would be close to the actual lift.

All precipitation fell in the Arctic air mass and lifting over the Arctic front may have been a possibility prior to 1230 GMT, February 2, when the Arctic front became so weak that it was dropped from the surface analysis (fig. 4). The remains of this weak Arctic front are indicated on the cross section for 1230 GMT, February 4 (fig. 10) but by this time it was well removed from the area of snowfall north of Midland. This is also true of the higher polar front. The position and slope of the polar front is not indicated on any of the other illustrations for other times but it may be inferred from the 500-mb. and 300-mb. charts. The position of the 500-mb. polar front usually corresponded closely to the position of the 20° C. isotherm at 500-mb. and the 300-mb. jet stream. It is seen in figures 11–15 that the precipitation fell to the north of both the 20° C. isotherm, where the thermal gradient began to increase, and the 300-mb. jet and hence to the north of the 500-mb. front.

For any precipitation in this geographical area (fig. 16), orographic lift must be considered as contributing to the total observed precipitation. It is difficult, if not impossible, to separate orographic precipitation from that caused by meteorological factors (see L. C. W. Bonacina [4]). For example, it is frequently observed that with surface isobars indicating upslope flow to the east of the Rockies, the actual winds blow at an angle greater than that required by frictional considerations and that the winds actually follow the topographic contours rather than the isobars. To have the wind more closely follow the isobaric contours and hence blow upslope, it appears that a meteorological mechanism is needed. On February 1 and 2, there was very little orographic lift as the low-level flow was very nearly parallel to the topographic contours. But on February 3, the upslope flow increased as the wind speeds increased and as the flow became more nearly normal to the topographic contours. The upslope flow reached a maximum on the 4th and decreased on the 5th to nearly the same as on the 3d. This trend agrees well with the trend in precipitation amounts given in table 1. The

TABLE 1.—*Computed vertical velocities and calculated 6-hour precipitation amounts compared with observed 6-hour precipitation*

1500 GMT	Vertical velocity 700–400 mb. cm. sec.$^{-1}$ (+ upward)	Calculated precipitation for 6 hours (inches)	Observed precipitation (inches) 1230–1830 GMT	
			Clovis, N. Mex.	Lubbock, Tex.
Feb. 1	2.7	0.00	T	T
Feb. 2	1.5	.04	(1)	T
Feb. 3	5.0	.03	0.05	0.02
Feb. 4	3.8	.00	.19	.06
Feb. 5	−1.5	.00	.02	.04

1 Missing.

strongest upflow into the area surrounding Clovis was about 2 cm. sec.$^{-1}$ and Showalter's [5] approximation for dewpoints of −8° C. at 900 mb. gives about 0.04 inches per hour, or for 6 hours 0.24 inches which is close to the observed.

Orography is not included in the model [6] presently used by the Joint Numerical Weather Prediction Unit, (JNWP) so that the vertical velocities calculated from this model do not include the initial vertical velocities that are due to upslope over the terrain. The vertical velocities calculated by JNWP were used to calculate precipitation with the hope that any precipitation not accounted for would be due to upslope. Of course, a discrepancy be-

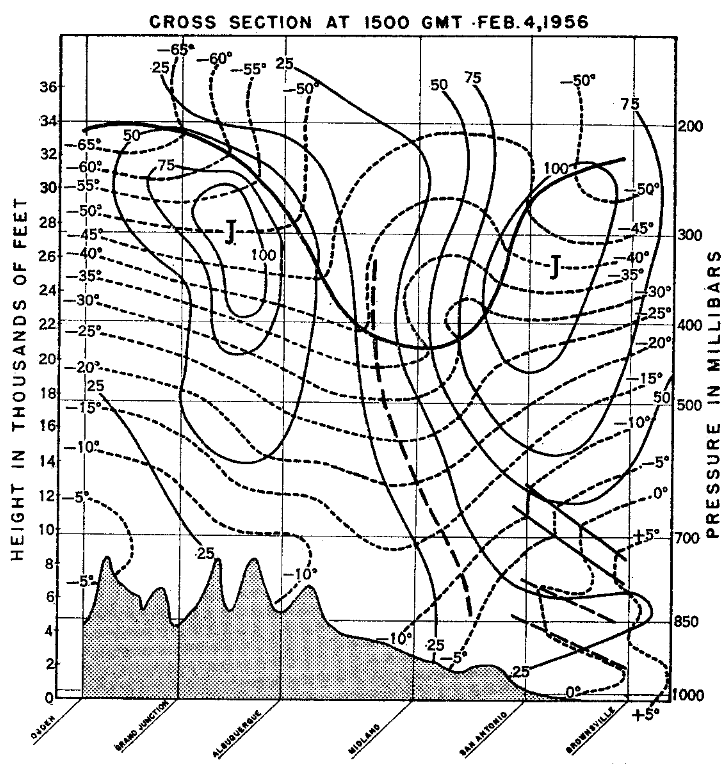

FIGURE 10.—Southeast-northwest vertical cross-section through the cold Low at 1500 GMT, February 4, 1956. Double heavy solid line is the polar front, single heavy solid line is the tropopause, double heavy dashed line is the Arctic front, and the single heavy dashed line is the vertical line of the Low. Lighter dashed lines are isotherms in ° C. and the lighter solid lines are isotachs for every 25 knots.

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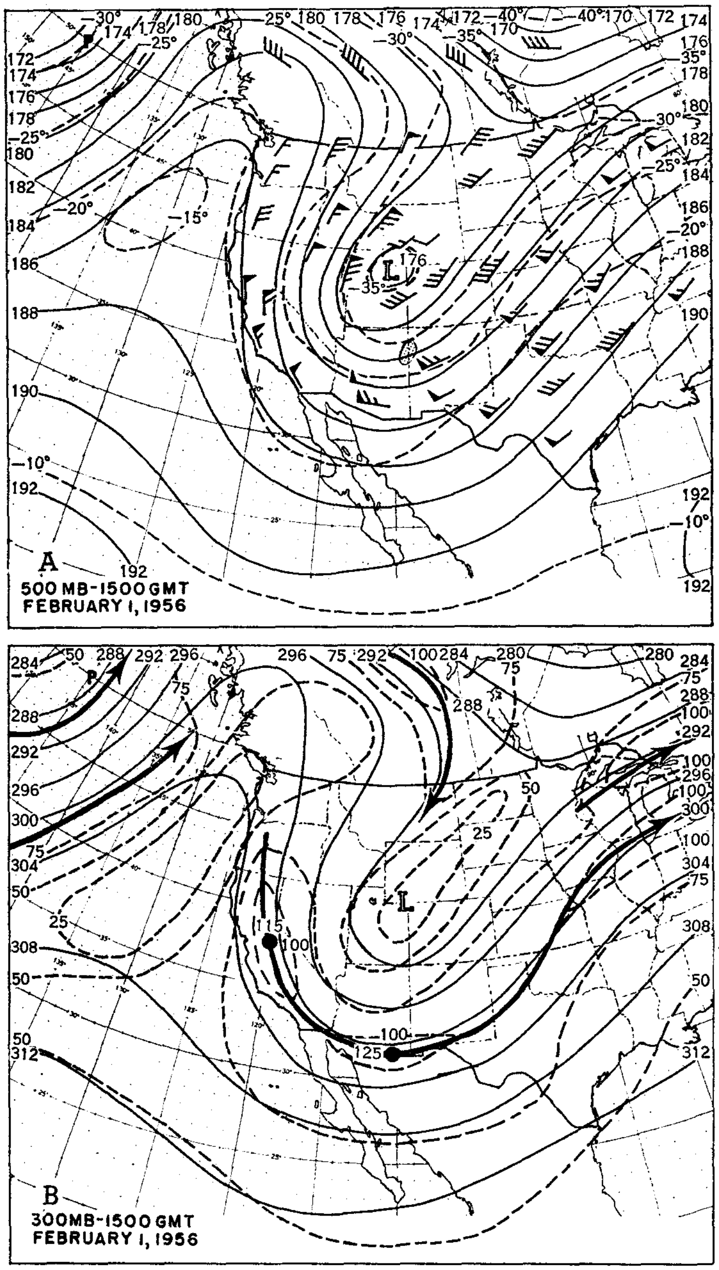

FIGURE 11.—(A) 500-mb. chart for 1500 GMT, February 1, 1956. Isotherms (dashed) are labeled in ° C.; height contours (solid) are in hundreds of feet. Shaded areas indicate regions where the accumulated snowfall was 6 inches or greater in the area shown in figure 2. Flags on wind shafts represent 50 knots, full barbs 10 knots, and half-barbs 5 knots. (B) 300-mb. chart for 1500 GMT, February 1, 1956. Heavy lines are the jets, dashed lines are isotachs in intervals of 25 knots. Light solid lines are height contours in hundreds of feet. Large dots indicate isotach maxima.

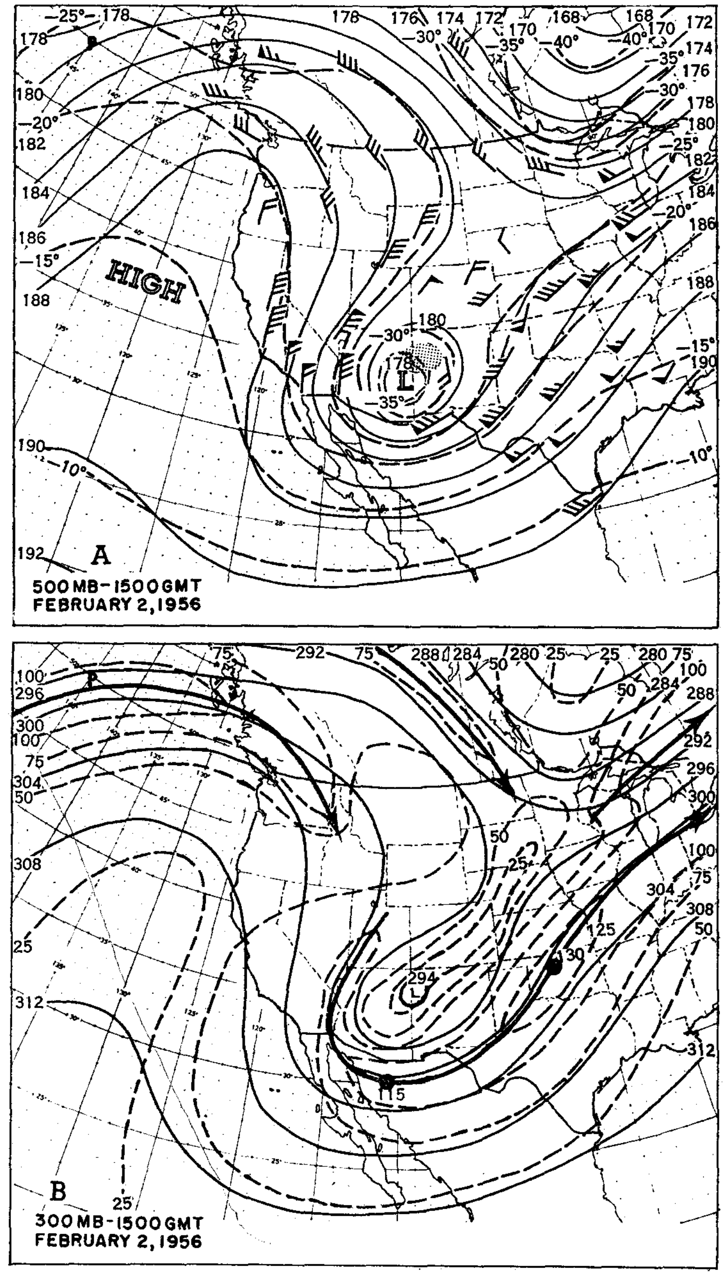

FIGURE 12.—1500 GMT, February 2, 1956. (A) 500-mb. chart. (B) 300-mb. chart.

tween observed and calculated precipitation would also result if the vertical velocities were too small, which they would be if potential instability was present or if the distance between grid points used by JNWP was too great [3]. For this case these two considerations are not believed to have affected the calculations.

The vertical velocities for the layer 900–700 mb. and 700–400 mb. were computed from the 1500 GMT data by JNWP as part of the initial analysis preparatory to the baroclinic prognosis and they include any lift that might be described as due to frontal lifting. For the calculations it might be better to use the vertical velocities for smaller layers, which might be estimated if the level of least divergence were known, but as it was not, the calculations are for just the two layers. The vertical velocities used were those over Clovis, N. Mex., which is in the center of the triangle formed by Amarillo, Albuquerque, and Midland (fig. 16), whose raob soundings were averaged to give the temperatures and dewpoint temperatures necessary for the calculations. The method of Thompson and Collins [7] which incorporates Fulks' [8] formula for rate of

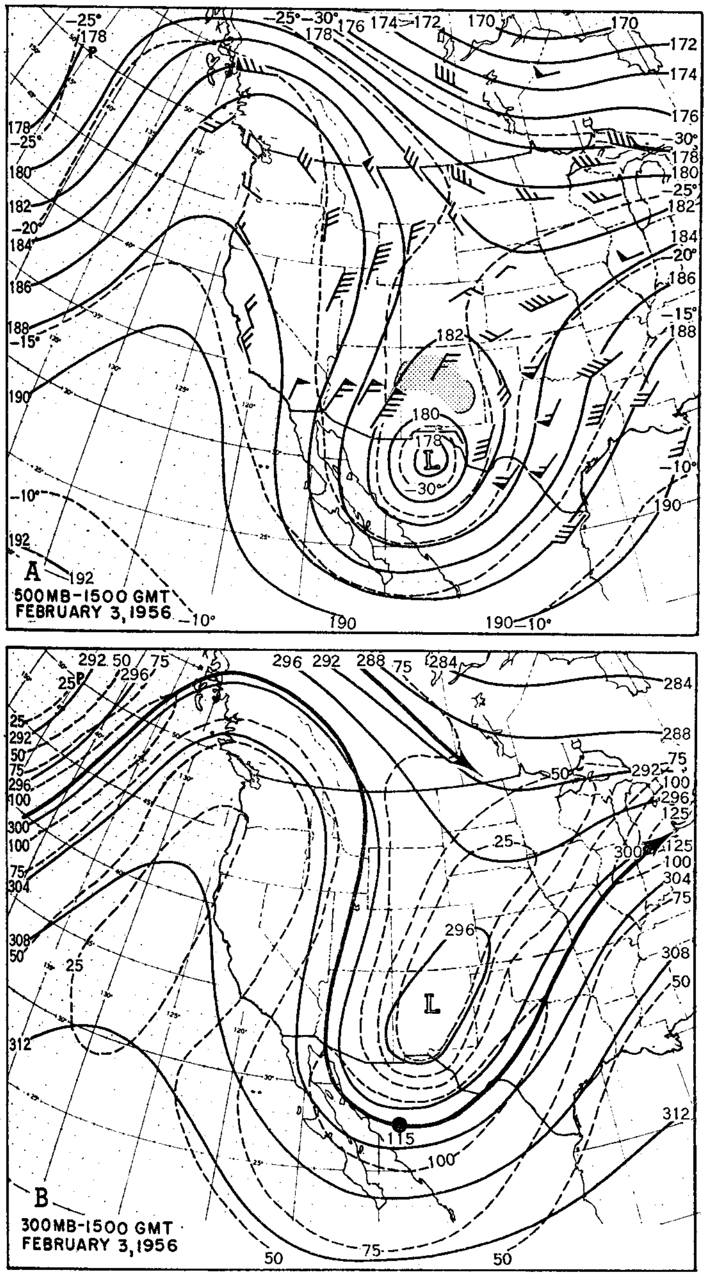

Figure 13.—1500 GMT, February 3, 1956. (A) 500-mb. chart. (B) 300-mb. chart.

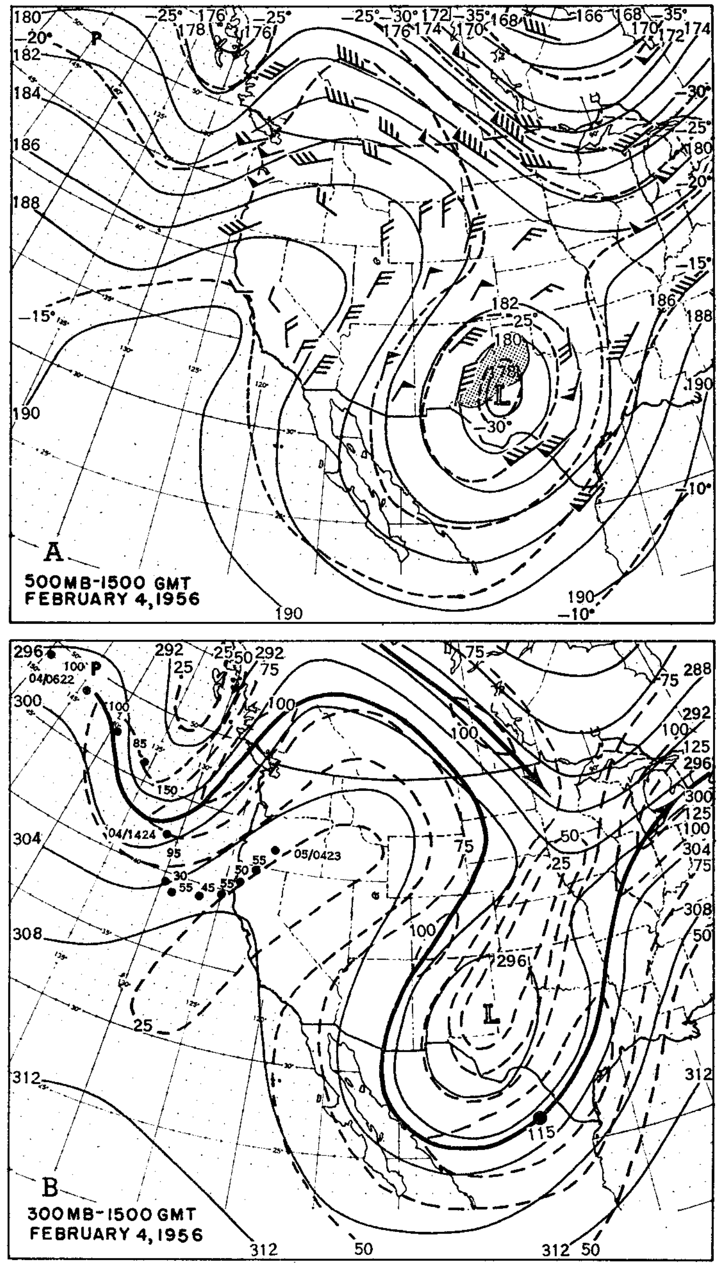

Figure 14.—1500 GMT, February 4, 1956. (A) 500-mb. chart. (B) 300-mb. chart. Small dots show path of transosonde with average speed in knots between positions. 04/1424 position is most nearly synoptic with the chart.

precipitation was used. The precipitation was calculated for a 6-hour period, rather than for the 12-hour period used by Thompson and Collins, under the arbitrary assumption that the calculated vertical velocities and averaged raobs for 1500 GMT were representative of the period 1230–1830 GMT for which precipitation amounts are available. The calculated precipitation amounts are representative of the area near the center of the triangle. The amounts at Clovis which is in the center may not be representative of this area so the amounts at Lubbock, Tex., were also included.

In none of the resulting calculations did the lower layer contribute to the precipitation as the velocity was not sufficient to lift the air to saturation. Also on February 1 and February 4 and 5 the vertical velocity in the upper layer was not sufficient to produce precipitation as is seen in table 1. On the 3d, the calculated amount agrees well with the observed. The largest amount on the 4th is not accounted for. Combining the initial velocity due to orography and the higher-level velocity from JNWP might come close to accounting for even the greatest intensity of snowfall observed.

For this type of circulation, the distribution of divergence is not clear from empirical studies or from dynamical reasoning. J. Bjerknes [9] says, ". . . and also the rain in the front half of a cold trough or a cold vortex are

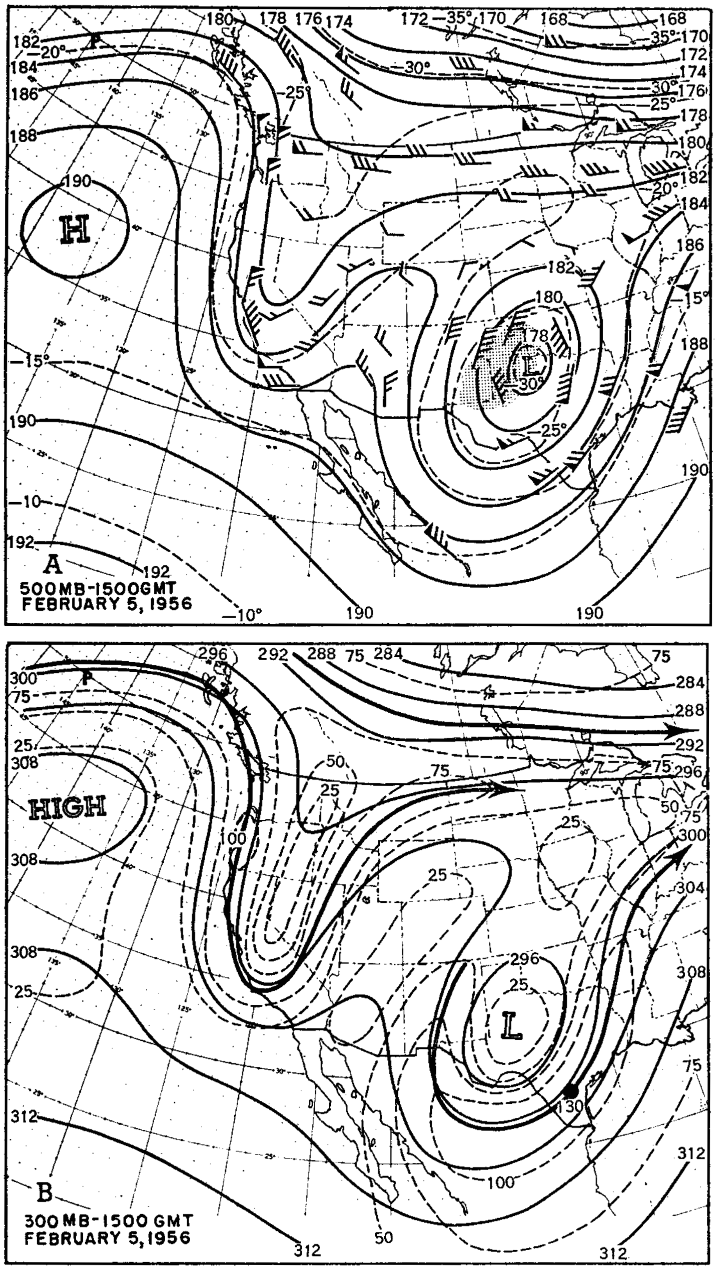

FIGURE 15.—1500 GMT, February 5, 1956. (A) 500-mb. chart. (B) 300-mb. chart.

probably to be explained by the general upward motion shown in Fig. 1." Figure 1 is his well-known model for the distribution of divergence above a frontal wave with the short wave trough in the westerlies above the surface wave. Palmén [10] states that cold upper Lows can be considered as a further development of the upper trough in the Bjerknes model. He also says that the mid-tropospheric Low has the structure characteristic of the fully occluded frontal cyclone although it is the result of processes other than the occlusion of wave-shaped frontal perturbations. J. Bjerknes has this to say of the fully occluded cyclone: "This sketch of the last part of the life cycle of cyclones is even less intimately related to exact dynamic theories than is the existing theory of frontal cyclogenesis."

From the cyclogenesis and low-level warming observed in the area of precipitation being considered here, low-level convergence certainly was present. If divergence aloft is needed as suggested by the Bjerknes model it is not possible to arrive at the first approximation, which depends on the relative strength of the "curvature and latitude effects" upon the wind speed [9], from an examination of the contour pattern. However, the latitude effect would increase as the flow around the Low became more southerly and stronger February 1–5 (figs. 11–15) and this would diminish any divergence due to curvature. This trend for diminishing divergence agrees with the decrease in vertical motion, February 3–5, in table 1. The heaviest precipitation was observed under the inflection points where the 300-mb. contours changed from cyclonic to anticyclonic. If the contour approximates a streamline and the Low aloft is a slow moving system with a relatively constant shape, this point is where the absolute vorticity is decreasing and where divergence would be expected if the curvature term of relative vorticity dominates the shear term (see Palmén [10]) and if an effect due to vertical wind shear and the rate of change of vertical velocity along the normal to the streamline can be neglected.

L. Sherman [11] disagrees with the reasoning of Palmén as applied to the mid-troposphere where it is the divergence that may be neglected rather than the effect of the vertical wind shear and the pattern of vertical velocity. In a cold Low aloft the vertical wind shear is typically positive, winds increasing with height, and for this he demonstrates that greater rising motion would be expected to the right of the inflection point of the jet stream than to the left. Thus precipitation would be observed to the right of the jet stream in the warmer air. In this case the precipitation was observed to the left of the jet stream and thus, if his hypothesis is correct, divergence aloft would not be the explanation for the lift and the resulting precipitation.

Another way of estimating upper-level divergence is from a consideration of the jet stream as suggested by Riehl et al. [12]. This effect must be thought of as being superimposed upon the divergence as estimated from the contours as a complete theoretical treatment combining the two effects is not available (see Bjerknes [9]). Around an isotach maximum along a straight jet, divergence is found in the front left quadrant and in the rear right, but Beebe and Bates [13] have pointed out that for a cyclonically curved jet one can be sure of divergence only in the front left quadrant. Inspection of the 300-mb. charts shows that on February 1, the precipitation area (fig. 11) was under the front left quadrant of the isotach maximum of the cyclonically curved jet stream. By 0300 GMT, February 2 (not shown) the jet maximum approached Amarillo and by 1500 GMT, February 2 (fig. 12) the area was under the left rear quadrant where for a cyclonically curved jet stream one can be sure of convergence, and hence the upward vertical motion and the precipitation

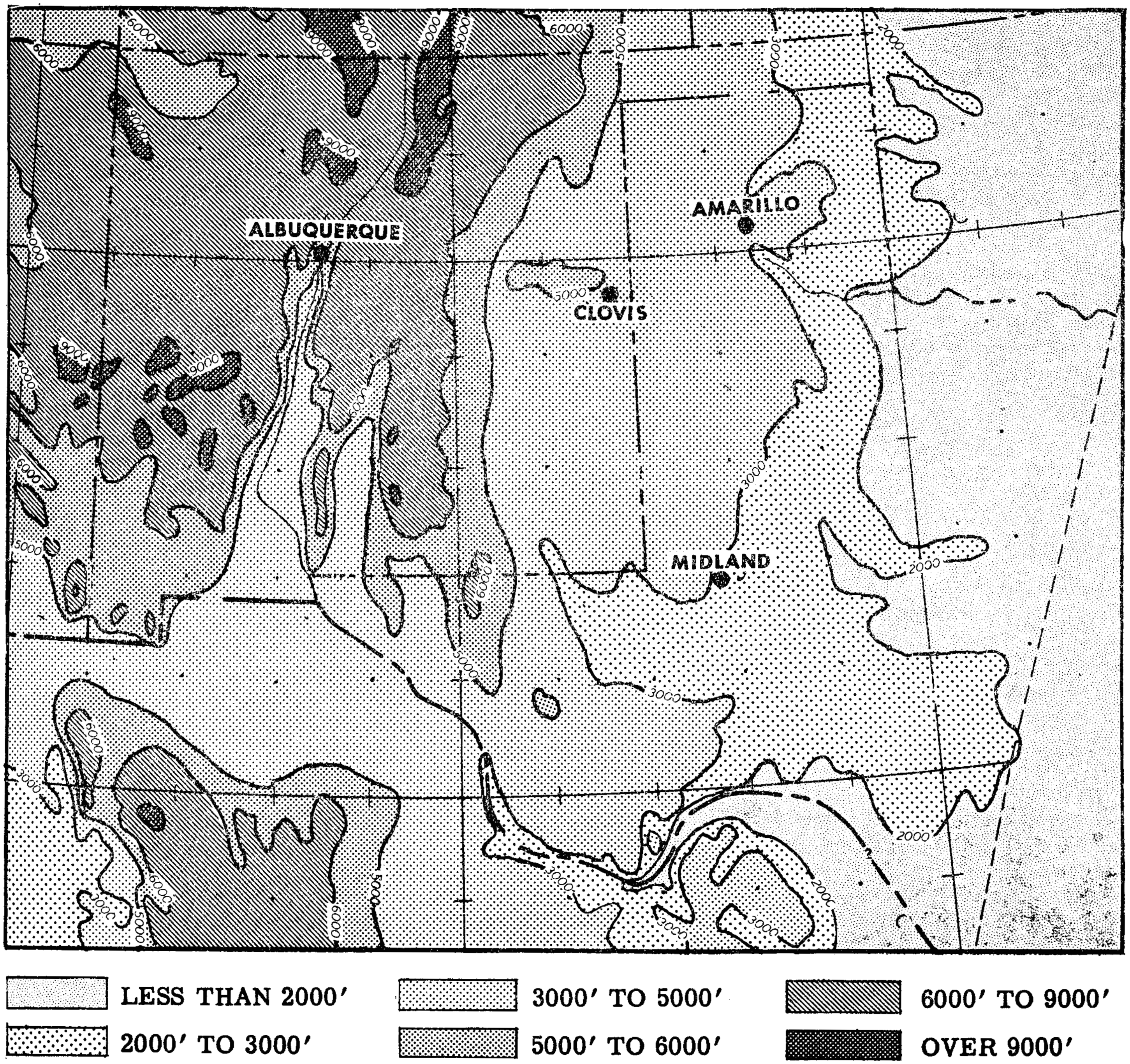

Figure 16.—Topographic map of the region affected by the storm of February 1–5, 1956.

should decrease. This change checks with a decrease in the calculated vertical velocities of February 1–2, in table 1. By 1500 GMT, February 3 (fig. 13), another isotach maximum had rotated around the Low so that once again the precipitation area was under the front left quadrant and the vertical velocities again increased (table 1.) The precipitation area remained in this quadrant February 4 and 5 (figs. 14 and 15).

Teweles [14] in a test relating this concept to precipitation, found that "on the eastern slope of the Rockies when precipitation occurs with upslope flow (easterly winds at low levels), there is no apparent association with any of these high-level synoptic patterns." However, in this case the high-level pattern may at least have been a contributing factor.

4. THE PROGNOSIS

It seems inconceivable that any forecast could be made for the heavy snowfall without knowledge of the movement of the Low aloft, particularly its 12-hour stagnation near Midland. A direct physical approach makes very stringent demands upon the accuracy of the prognosis, but even an empirical approach would need this knowledge, even though the effect of the Low aloft might be indirect insofar as it helps to determine the surface flow.

An excellent objective aid to the analyst making a 500-mb. prognosis is the Wilson grid method [15] for forecasting the movement of the center of a cold Low aloft. At the National Weather Analysis Center (NWAC) the Wilson prognosis for 24 hours is extrapolated for another 12 hours and such 36-hour prognoses, which were made for this article after the verification time, are included in figure 3A. The analyst also has the use of a 48-hour barotropic prognosis and a 36-hour baroclinic prognosis prepared by JNWP both verifying at the same time. The positions of the center of the Low aloft from these and the NWAC prognosis made operationally are presented in figure 3B. During the early part of the southward plunge of the Low aloft while it was not yet completely "cutoff", the baroclinic prognosis gave the best forecast. During the last part of the plunge, after it was completely "cutoff," the 48-hour barotropic and the 36-hour Wilson, which is also barotropic, gave equal results. After the Low aloft recurved both barotropic prognoses consistently forecast it too far south and too fast. The baroclinic effects were becoming greater as surface cyclogenesis was occurring during this period. However, the JNWP baroclinic prognosis did not forecast the Low aloft to be near Midland at 0300 GMT, February 4, while the NWAC verifying position was very close. Both NWAC and JNWP baroclinic prognoses erred in accelerating the Low too rapidly out of the Midland area, although the JNWP was slightly better.

No later than 1500 GMT, February 3 was it apparent that the Low aloft would eventually move eastward and accelerate as the trough aloft near ship "P" (fig. 13) continued to move eastward and change the flow aloft over western United States to a more westerly flow. This acceleration should not have been called for until the prognosis made from the chart of 0300 GMT, February 4 to verify 1500 GMT, February 5. At this very crucial time the trough aloft passed ship "P" and was in an area of no data and as a consequence the analysis failed to show the trough far enough east or as intense as it was shown to be by subsequent events. On the 300-mb. chart for 1500 GMT, February 5 (fig. 15B) note the intensity of the trough as compared to 1500 GMT, February 4 (fig. 14B) and note also the 100-knot isotach maximum in the northwest flow on the 5th as compared to a 50-knot plus maximum on the 4th. It might be argued that the trough had intensified in this period if it were not for experimental data not available in time for the original analysis. Part of the track of a balloon flying at constant pressure, a transosonde [16], is given on the 300-mb. chart for 1500 GMT, February 4 (fig. 14B). From this it is seen that at this time the trough was deeper than analyzed and the 100-knot northwest winds already existed. This might well have prompted the analyst to forecast the acceleration even sooner increasing the prognosis error especially after the Low moved rapidly northeastward for 12 hours after 1500 GMT, February 3. Regardless of whether the original or revised analysis is used, the application of Henry's rule [17] gives good results. That is that a cold Low aloft in the southwestern United States should not be forecast to move until the katallobaric center with the trough aloft to the northwest comes within 1200 nautical miles of the Low.

None of the surface prognoses of NWAC or the 1,000-mb. prognoses of JNWP forecasted an upslope wind of the magnitude observed during the time of maximum upslope. This might be expected from the fact that the 500-mb. prognoses were in error and that the prognoses are vertically consistent. Of course, even with a poor 500-mb. prognosis the surface prognosis might be better if the thickness prognosis had a compensating error.

It would be of great interest to see if any other models suitable for numerical weather prediction would have given a better prognosis than any of those discussed here.

5. SUMMARY

1. The heavy snow cover over the South Plains of Texas was due to the long duration of a light-intensity snowfall.

2. The light-intensity snow resulted from the adiabatic lifting of a stable air mass which had a constant supply of moisture. The lift was associated with a cold Low aloft which produced a flow pattern favorable for upslope motion.

3. The duration resulted from the slow movement of the Low aloft over the area.

4. Any approach to forecasting the snow cover, whether it be physical or empirical, depends upon an accurate prognosis of the position of the Low aloft, although this in no way would insure a perfect forecast.

5. In this case no available method appeared consistently to give prognoses which were sufficiently accurate.

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